APPLICATION OF ECONOMIC TECHNIQUES TO FIRE MANAGEMENT – A STATUS REVIEW AND EVALUATION

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FIRE IN MULTIPLE USE MANAGEMENT RD&A PROGRAM

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RESEARCH SUMMARY

The USDA Forest Service policy adopted in 1935 calls for fast, aggressive fire suppression action. Economic considerations, first voiced in 1916, quieted after 1935, until the 1960's and 1970's. The most common technique proposed is least-cost-plus-loss; the objective is to minimize the sum of all suppression and presuppression and resource losses. Another technique, benefit/cost analysis, differs only slightly. The benefits of fire control are the values protected less the resource losses; thus, least-cost-plus-loss and benefit/cost analysis will yield similar results. A third technique often proposed, the allowable burn objective, is usually not based on economic criteria and, therefore, is not discussed in depth. For any economic technique, accurate damage appraisal is needed. Appraisals are often restricted to timber because of the intangible nature of other resources. Since 1945, several attempts at complete resource damage appraisal systems have been attempted, but few have been widely applied due to the complexity of such systems.

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INTRODUCTION

Anyone who has searched for literature pertaining to fire economics will have realized a fundamental problem: a field of "fire economics" does not exist. Fire economics is not a special discipline like silviculture or entomology, but forest or agricultural economics applied to fire protection or fire management[1] on a limited basis.

In general, economics is concerned with the allocation of limited resources or inputs to the accomplishment of unlimited goals. It follows that fire economics is concerned with determining the share of resources to be allocated to fire management and how this share should be distributed among various fire management activities. It is assumed that fire management contributes to meeting land management objectives[2]; only in this light is fire economics of value. The Forest and Rangeland Renewable Resources Planning Act (RPA) of 1974 requires that forest resource planning integrate all its various programs, which in turn involves fire management, including both fire exclusion and prescribed burning.[3] Hughes (1976) highlights the RPA's intent with respect to the planning function:

> ". . . there was an apparent need for a Forest Service-wide <u>planning process</u> which encompassed all programs and which required explicit evaluation of program alternatives related to equally explicit goals. There are and have been various planning processes in all Forest Service program areas. Some are the result of technical requirements; some are the result of a wide variety of minor legislative and administrative requirements; some are linked to interagency planning activities; and some are related apparently only to the practical exigencies of preparing annual justification statements in the budget process. What has been absent, however, is an overall planning framework for relating the parts to the whole. The RPA provides this heretofore missing framework for all Forest Service planning."

To integrate fire planning in natural resource management planning, we must first recognize the relationships of fire management to the commodities and services the forest provides. One obvious forest product is wood fiber. In addition, some forests have aesthetic value, provide recreational opportunities, forage for domestic stock, and habitat for wildlife, and influence the quality and quantity of water available for human consumption, irrigation, and industrial needs. Fire management is a support function; it may either help or hinder efforts to provide forest commodities; thus, the "product" of fire management is measured in units like board feet, AUM's, or simply acres. Fire planning, ideally, facilitates meeting these output-oriented goals. Economics is the rationing function, allocating resources among all competing management activities, including fire management, for a maximum return within legal and policy constraints.

Inquiry into the economics of fire control and fire use has been limited because fire control organizations, while having to compete for some of their money, have also

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[1]Fire management being used in this paper to mean "the integrating of fire-related biological, ecological, physical, and technological information into land management to meet desired objectives" (Barney 1975).

[2]Charles F. Roberts. 1976. Some considerations for fire and land use planning. Mimeo.

[3]"Prescribed fire" will be used herein to mean any fire that is allowed to burn, regardless of the means of ignition.

been funded substantially on a "blank check" by Forest Fire Fighting (FFF) funds. Because the funds are allocated after expenditures for suppression, some presuppression, and a limited amount of rehabilitation costs, competition for funds was of less concern in fire planning than for other forms of management. The attitudes behind this kind of funding have been changing, as illustrated by the change from Protection and Maintenance (P&M) funds with FFF funds to the new Fire Management (FM) funds. Fire is beginning to be seen as a process that has desirable or undesirable effects in terms of land-use goals and service and commodity flows. This idea is replacing the view that fire control objectives can be determined independent of land-use goals and service and commodity flows. Consequently, economics has become a more important factor in evaluating fire management planning and policy.

This report is divided into three sections. The first section examines the role of economic thought in the formation and development of USDA Forest Service fire policy. The second section discusses the development and application of economic guidelines for investment in fire management activities. Much of section two is concerned with economic models for optimizing expenditure on fire management or for examining the cost effectiveness of such expenditure. The third section discusses the considerations necessary and the methods developed for the economic appraisal of fire effects, both destructive and beneficial. This section is limited to fire damage appraisals, and therefore does not include literature on the methods of valuing resources for purposes other than fire damage appraisal. A partial listing of works that deal with resource valuation not specific to damage appraisal is included in the appendix.

ECONOMICS AND THE DEVELOPMENT OF FIRE POLICY IN THE FOREST SERVICE

The USDA Forest Service was formed by the Transfer Act of 1905[4] with, initially, no definitive fire policy. There was, however, concern that something needed to be done about destructive conflagrations, such as the Miramichi and Maine fires in 1825, the Peshtigo in 1871, the Michigan in 1881, and the Wisconsin in 1894, the smallest of which was one million acres (Brown and Davis 1973). The issue of conflagrations was brought up repeatedly in the ensuing decades. Loveridge (1944) attributed much of the need for development of fire policy to dry weather cycles that aggravated the fire occurrence and spread problems and led to greater resource losses. He was primarily concerned about damage, but a great deal was also written during the twenties and thirties that dealt with how much protection was justified. Headley (1916), Sparhawk (1925), and Flint (1924; 1928) were the first to express these concerns in terms of economic or financial constraints. Much of the foundation for economic analysis of fire control was laid by these three writers, and by Hornby (1936) and Gisborne (1939) who continued the theme.

The so-called 10:00 a.m. policy was born in a meeting of Regional Foresters in 1935, following two severe fire seasons in the Pacific Northwest that killed several firefighters and destroyed timber on more than a half-million acres. Strong reactions to these and other disastrous fires prompted approval of a no-nonsense policy for the National Forests (Baker n.d.):

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[4]Transfer Act of February 1, 1905; 33 Stat. 628, 16 USC 472, 524, 554. The Organic Act of 1897 allowed for the establishment of National Forests, but not for their administration. The Transfer Act moved the National Forests from the Department of the Interior to the Department of Agriculture as well as providing for the administration of the National Forests.

"The approved protection policy on the National Forests calls for fast, energetic, and thorough suppression of all fires in all locations, during possibly dangerous fire weather.

"When immediate control is not thus attained, the policy then calls for prompt calculating of the problems of the existing situation and probabilities of spread, and organizing to control every such fire within the first work period. Failing in this effort, the attack each succeeding day will be planned and executed with the aim, without reservation, of obtaining control before ten o'clock of the next morning."

The 10:00 a.m. policy implies that wildfire protection is worth whatever it costs or that the values protected[5] are almost immeasurably large. At the time, this assumption was not unreasonable. Loss of life from wildfire was a serious threat; the Peshtigo fire alone killed 1,500 people. Loss of resources from large conflagrations, particularly in timber, also was viewed as critical. Thus many of the writers voicing their opinions accepted the policy as economically sound. Hornby, writing in 1936, said:

"Attention is directed to the fact that no conflict exists between the three major objectives of fire control that have been widely recognized. Consequently, for planning purposes, the following composite objective was used. By attempting to 'Control every fire in the first work period,' it is hoped to keep burned acreage within the 'Permissable-percentage-of-burned-area,' and ultimately to make the sum of fire-control costs and losses most 'economical'."

The 10:00 a.m. policy silenced those who sought new rules for allocating funds to fire control. Primary emphasis was on efficient fire-control organizations, reducing burned acreage, and fire prevention. With the exception of Craig and others (1945; 1946a; 1946b) and Arnold (1949), few people in American forestry expressed concern with economically justifiable levels of protection and control until the mid-1960's, when Mactavish, working for the Department of Forestry of Canada, picked up essentially where Sparhawk and Flint had left off.

Alternatives to the 10:00 a.m. policy received little attention for over 30 years; the policy was evidently considered appropriate till the late sixties and seventies. In the last 10 years, the policy has received a great deal of critical reexamination and the volume of economics literature in fire control (or fire management, as it has become) has expanded. The "fire economics" literature to date reveals little theoretical deviation from the least-cost-plus-loss economic model proposed by Headley in 1916 and developed by Sparhawk in 1925. These documents remain viable even on "the new frontier" of fire management economics.

Ed. Note: Since this paper was prepared, the long-standing 10:00 am policy has been replaced. Fire management policy now specifies a fire protection and use program that is cost effective and is responsive to resource management goals.

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[5]For this paper, "'value protected' is the maximum potential resource value that can be destroyed by fire on a resource management unit. This would reflect the maximum potential firecaused reduction in goal attainment." (Crosby 1977, p. 2)

ECONOMIC GUIDELINES FOR INVESTMENT IN FIRE MANAGEMENT

Many authors have been concerned with the economically justifiable level of expenditures on fire management. Several models have been developed as economic guidelines for such determinations. The most widely discussed model is least-cost-plus-loss: the level of expenditure that minimizes the sum of all costs and losses. A model that yields similar results is benefit/cost analysis; however, this method allows comparison of fire management cost effectiveness with the cost effectiveness of other types of management. Several other models, including the allowable burn objective, are briefly discussed in the section.

Least-Cost-Plus-Loss: Theoretical Approaches

The most widely accepted and frequently mentioned system of determining the optimal expenditures for fire management is the least-cost-plus-loss method. This method has been modified in accordance with the fire management activities that are considered critical--attack time, presuppression effort, or fire management effort. But the fundamental approach is that protection level is optimized when the combined costs of prevention (including presuppression), suppression, and damage are minimized. These three functions are assumed to vary predictably with changing levels of presuppression expenditure, fire management effort, or acreage burned. If presuppression expenditure is used as the independent variable input, for example, resource damage is seen as a decreasing function. In other words, as the presuppression level is increased, fire damage decreases. Suppression costs, logically, also decrease with increasing presuppression. Prevention expenditure, in this framework, is obviously as increasing function. The resulting combined function is a u-shaped curve, with the minimum point representing the optimum presuppression expenditure.

The least-cost-plus-loss approach is closely related to benefit/cost analysis, another familiar technique used to evaluate investment alternatives. The similarity lies in the concept of value protected: the two components of value protected are actual resource damages and damages averted. At any practical level of protection, some damage is sustained, while some is prevented. With no protection, theoretically, damages averted are zero, and all the values protected are lost. Benefit/cost analysis uses damages averted as its measure of benefit, to be compared to protection costs. The least-cost-plus-loss approach uses actual damages as a component of the costs to be minimized. Either method, using various presuppression levels (for an example) and measuring marginal changes, will give the same result. However, least-cost-plus-loss is used much more frequently in fire economics literature than benefit/cost because of the preceived difficulty of defining "value protected" and measuring damage averted. Given that fire has some probability of destroying or damaging resources, value protected is a viable concept. However, until this probability can be explicitly defined, the value protected (and in turn, damage averted) is not measurable. Actual damages are probably easier to assess, though this does not imply that such measurement is simple to do.

One of the first least-cost-plus-loss models to be developed was by Sparhawk 1925). Its basic principle is to minimize the sum of "total liability" (suppression cost plus resource losses) and primary protection cost (presuppression), treating presuppression expenditure as the independent variable that determines suppression costs and damage. Sparhawk's conception of these two functions is shown in figure 1.

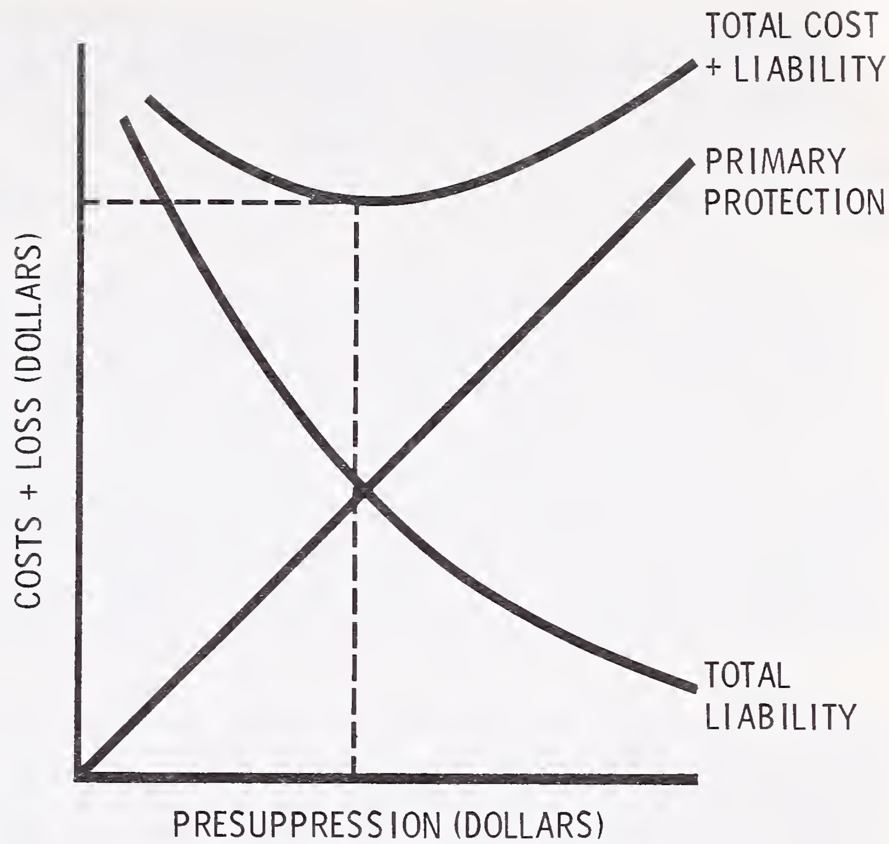

Figure 1.--Sparhawk's total liability function.

Total liability is, in this model, dependent on fire hazard, which in turn may be influenced by presuppression efforts that change resistance to control, manpower availability, "accessibility" (including transportation networks and detection facilities), or suppression efficiency (personnel training). An improvement in any of these parameters results in a decrease in area burned. Increases in primary protection expenditures also reduce resource losses by decreasing the expected area burned and the probable destruction if burned. Thus total liability as a whole is inversely related to primary protection efforts. The sum of primary protection and total liability is the actual cost-plus-loss function to be minimized.

Sparhawk identified timber and forage as protected values and watershed, soil, recreation, and wildlife as indirect values. In application, however, he used only the stumpage value. His reason for limiting losses to timber was "...not only because of the extreme paucity of data (for other resources), but also because the existing data indicate that such damage is less than the probable error in estimating damage to timber." No specific attention was given to the potential beneficial effects of fire.

Flint (1928) was the next to mention the least-cost-plus-loss approach. His method of arriving at the least-cost-plus-loss is essentially no different than Sparhawk's; he also makes presuppression expenditure his independent variable, though he expresses it in cents-per-acre protected instead of total spending. This is because he feels that area burned over is a more reliable indicator of fire damage than total value losses, although his reasoning is unclear. One clue might be that, in talking about losses, Flint mentions only timber value losses, "from old official records, probably not exact but believed fairly dependable." It is possible that these only included stumpage values lost, though this was not specified. At any rate, Flint preferred to put expenditures and losses on a per-acre basis and minimize the total to reach the objective of "adequate protection," defined as:

". . .that degree of protection which will render forest property as safe on the average from destruction by fire as are other forms of destructible property in which moderately conservative investors are willing to place their funds."

Flint felt that the least-cost-plus-loss solution based on "ample and dependable" data would be able to determine "adequate protection."

Hornby (1936) used a modified version of Sparhawk's approach based on using acreage burned rather than presuppression expenditure as the independent variable, as shown in figure 2. Damages and suppression costs, in this model, increase with increasing area burned. Presuppression expenditures, on the other hand, are inversely related to burned area. Hornby was convinced that the least-cost-plus-loss approach was sound but that damages were difficult to measure as a function of presuppression effort. He suggested, instead, experimenting with various levels of suppression, presuppression, and resulting damage in different time periods and using whatever combination yielded the least-cost-plus-loss figure. It was his belief that the 10:00 a.m. policy would approach this solution during critical burning periods.

Headley (1943) provides the first attempt at a thorough analysis of fire-control policy alternatives. He was concerned primarily with human values--how forest resources serve human needs--and thus regards those objectives that deal only with acreage or time constraints as unrealistic because of the lack of consistency with the changing natures of human needs and resource values. He accepts least-cost-plus-loss because it does focus on human values and takes into account the fact that forests, in serving a variety of human needs, have different values over different times and areas. In other words, least-cost-plus-loss is adaptable to changing conditions in application, while tolerable area-burned or control-time objectives are less dynamic.

Craig and others revived the model again in 1945 and 1946 in the Southern Appalachian area. Although their studies were primarily empirical and oriented toward application, their contributions to least-cost-plus-loss theory were also substantial. This group of reports is the first to attempt specific damage appraisal in terms of multiple resources and one of only a few that did more than recognized values other

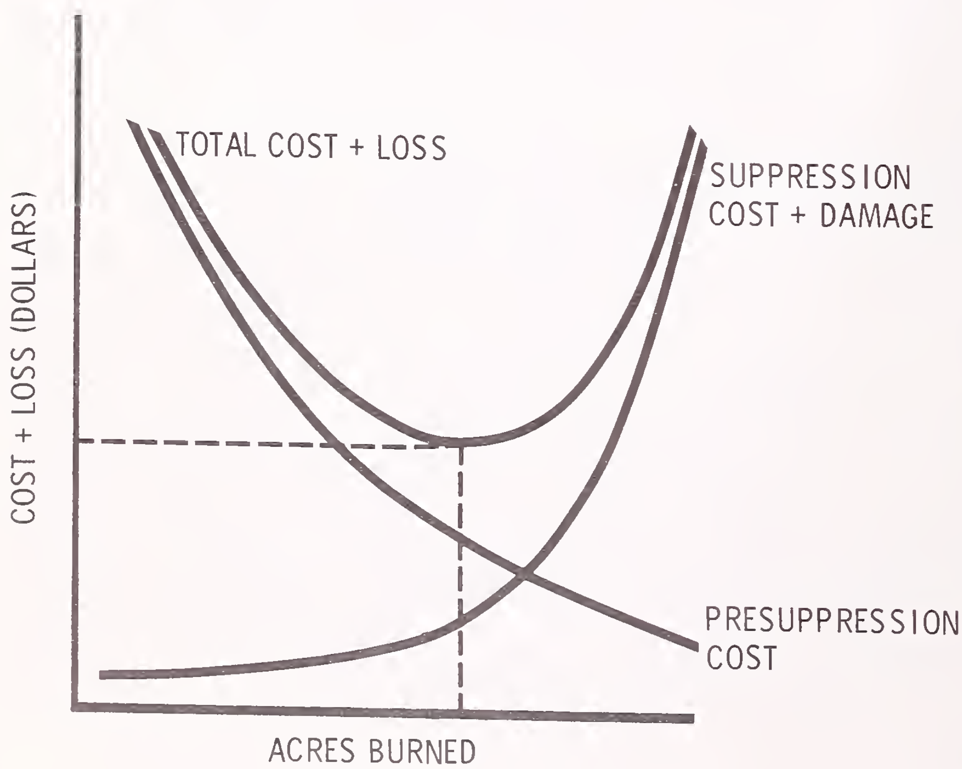

Figure 2.--Hornby's least-cost-plus-loss model.

than timber. Using a composite estimate of damage, then, Craig proposes comparing expenditures for suppression and presuppression with damage figures to insure that dollar increments of control (presuppression and prevention) expenditure result in at least an equivalent reduction of loss (damage and suppression). In terms of theory, Craig's major contribution is that he recognizes the need for marginal analysis; he suggests comparing several different levels of cost-plus-loss at the margin to determine a reasonable range of protection.

Arnold (1949) analyzes a number of objectives dealing with adequate fire control, and decides that least-cost-plus-loss is preferable to objectives based on allowable burned area or some measure of control time. He cites Sparhawk, Flint, and Craig as attempts to apply this method, but points out the inadequacy of their cost data and information on resource damage. He proposes a variation of least-cost-plus-loss which will minimize the problems identified. Initially, he assumes certain functional relationships among variables: suppression cost (S) depends on the number of men dispatched and the length of time fire is burning before their arrival (attack time), presuppression (P) is inversely related to attack time (which he calls hour-control or elapsed time between detection and attack), and damage (L) is a constant per acre burned. The model is built around a world of homogeneous fuels, predictable fires, and constant fire weather.

Arnold derives suppression-cost-plus-damage for a number of presuppression levels, measured by attack time. His independent variable is suppression-force size, which he optimizes for each attack time selected. He then derives total cost-plus-loss curves over a range of attack times which include presuppression costs and prevention costs as well as suppression costs and resource losses (figure 3). Prevention, which in this model is aimed at reducing fire occurrence, can be applied uniformly (a "shotgun approach") or concentrated on trouble spots. Optimal prevention levels are determined in much the same manner as optimal suppression-plus-loss figures using a percentage reduction in the number of fires as the independent variable, again over a range of attack times.

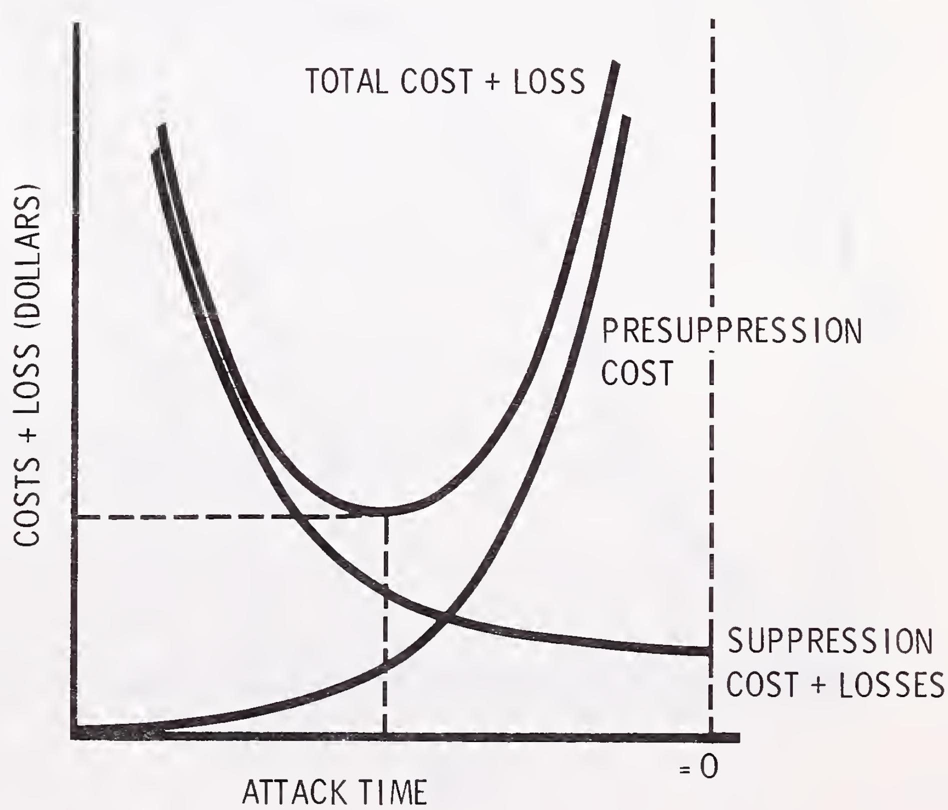

Figure 3.--Arnold's least-cost-plus-loss model.

Mactavish (1965) works with an expanded version of Arnold's model. In an attempt to introduce more realism, he adds in weighted averages of two stochastic variables as needed data: a frequency distribution of fire intensity and the probability of concurrent fires. He sees the suppression costs as an increasing function of crew size for a range of fire intensities, and the suppression-cost-plus-damage function as directly related to elapsed time from detection to initial attack for each intensity. Presuppression costs (detection, road building, and so on) are inversely related to elapsed time. The minimum of the sum of these two functions gives the optimum cost-plus-loss and elapsed time (attack time). While the Mactavish approach is conceptually more realistic, he suggests that various data are needed before it can be implemented in planning.

Parks (1964) also proposed the least-cost-plus-loss method as the objective of fire control organization. His efforts were directed primarily toward identifying cost relationships in fire, assuming initially that damage-per-acre is directly proportional to area burned and, therefore, that a major purpose of fire control should be to keep all fires from blowing up. The pattern of fire growth that Parks proposed is shown in figure 4, where:

T_I = ignition time

T_D = detection time

T_A = attack time

T_C = control time

T_M = mopup time

T_F = final extinction time.

The most critical time elements are those of detection, attack, and control; thus the critical cost factors are identified as follows:

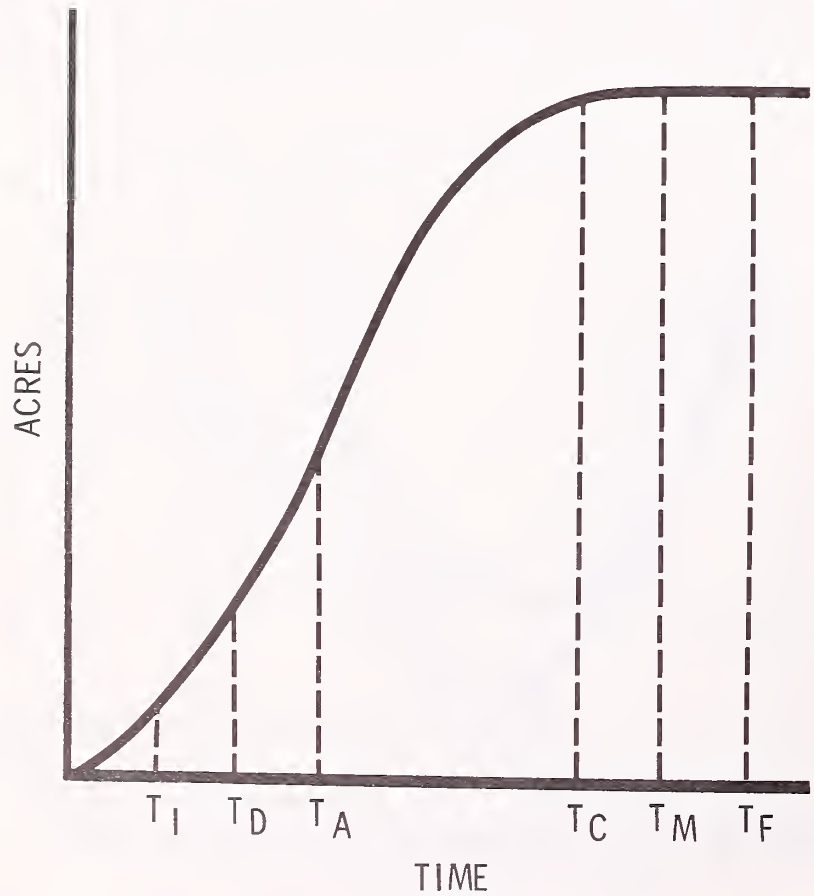

Figure 4.--Parks' pattern of fire growth.

1. "One-time" costs (transportation, logistics) proportional to the size of the suppression force (assumed function: linear),

2. Cost of other emergency support (communications, police, etc.) while the fire is out of control,

3. Cost in dollars per man-hour of suppression force (wages, equipment, etc.) proportional to total suppression time required,

4. Costs of maintaining fire-control organization level (assumed function: constant), and

5. Costs of resource damage per acre (assumed function: constant at an arbitrary level).

Because the variable costs and losses involved are, according to Parks, proportional to the size of the fire and control time, the policy implication is clearly that of speedy and energetic initial attack. Parks' model does not recognize any beneficial effects of fire and, thus, limits policy options; it does not differentiate between resource damages on units with different land-use goals, and it assumes that the level of presuppression is fixed.

In this sense, Parks' model is analogous to the first step of Arnold's model, in that it examines only minimum suppression-cost-plus-loss, and does not include optimal presuppression or prevention in the solution. Gamache (1969) later extended Parks' model to include changes in presuppression levels and, thus, arrives at a model very similar to Arnold's. Because Parks more or less ignores considerations other than suppression, and given his assumption that damage is a function of area burned, it is no surprise that the fire control policy implications in his paper were fully in accord with the actual policy.

Davis (1971) compared fire protection to insect and disease control, flood control, national defense, and city police and fire departments in the sense that all have similar objectives (namely, to prevent something from happening) and outputs (non-losses). In addition, all can be treated by the least-cost-plus-loss model. Davis, however, recognizes some of the limitations of the model for the first time. There are three sorts of problems: estimating costs, estimating damages, and associating changes in costs with changes in damages. Estimating costs, he says, is the easiest task, although care should be taken to keep data comparable over time and to record how all funds are used. The problem of damage estimation is not so simple; Davis mentioned that most efforts to date had considered only market commodities, and very little had been done to identify or evaluate intangible or "psychological" damages. Finally, Davis assesses the problem of associating changes in costs with changes in damages:

> "To make any comparisons at all, we need good time series data on expenditure levels and damage levels for the protected area in question. More than this, however, we need a good crystal ball. . . The big problem is that we do not really have a good way of estimating (damage with zero organized presuppression effort)."

In a memo, Boster[6] pointed out the potential inconsistency of the least-cost-plus-loss method with the objective of reducing area burned, both of which are program objectives of Forest Fire Prevention and Protection of National Forests. Reducing acres burned below the minimum point of the sum of damages and protection costs will cause this sum to rise above its minimum dollar amount. In other words, these two

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[6]Ron S. Boster. 1976. Transmittal of fire policy report to Adrien Gilbert, policy analysis. June 18, 1976.

objectives are mutually exclusive over some relevant range of control. In 1967, the Office of Emergency Planning, in its report to Congress, stated, "The study vividly brought to sharp focus the fact that reduction of total burned acreage, by itself, is not the full measure of effective fire control" (U.S. Dep. HEW 1967, p. 6). This inconsistency, according to Boster, is a result of the "lopsided" way in which the Forest Service has traditionally viewed resource damage, the scanty recognition given to fire benefits, and the tendency to ignore costs and concentrate on reducing burned acreage. To measure effectiveness, then, Boster suggests the objective should be to maximize the difference between damage averted and cost; stated another way, this means minimizing actual damages plus costs.

Simard (1976) takes a more theoretical approach. He recognizes two faults or sources of confusion in previous works. First, there has been little consistency in defining the independent variable. Moreover, ". . .the (cost-plus-loss) diagram remains little altered regardless of how the horizontal axis is defined." Second, the relationships of cost and damage functions with their underlying production function have never been explicity examined. He develops a hypothetical production function for area burned in terms of "fire management effort" and contends that this may be translated into the traditional minimum cost-plus-loss model (in terms of either acres burned or fire management effort) or analyzed by marginal analysis: equating the marginal cost of "units of fire management effort" with "marginal damage" (fig. 5). Simard labels this function "marginal damage," represented by the first derivative (slope) of the production function. This is more than an extension of existing theory; it is a new application of production economics. It is also consistent with micro-economic optimization techniques used for other forms of production, and in terms of economic theory it is quite sound. In addition, Simard's model is the first to treat beneficial effects of fire by the same analytical technique, thus including a greater part of the fire management picture than any other approach to date.

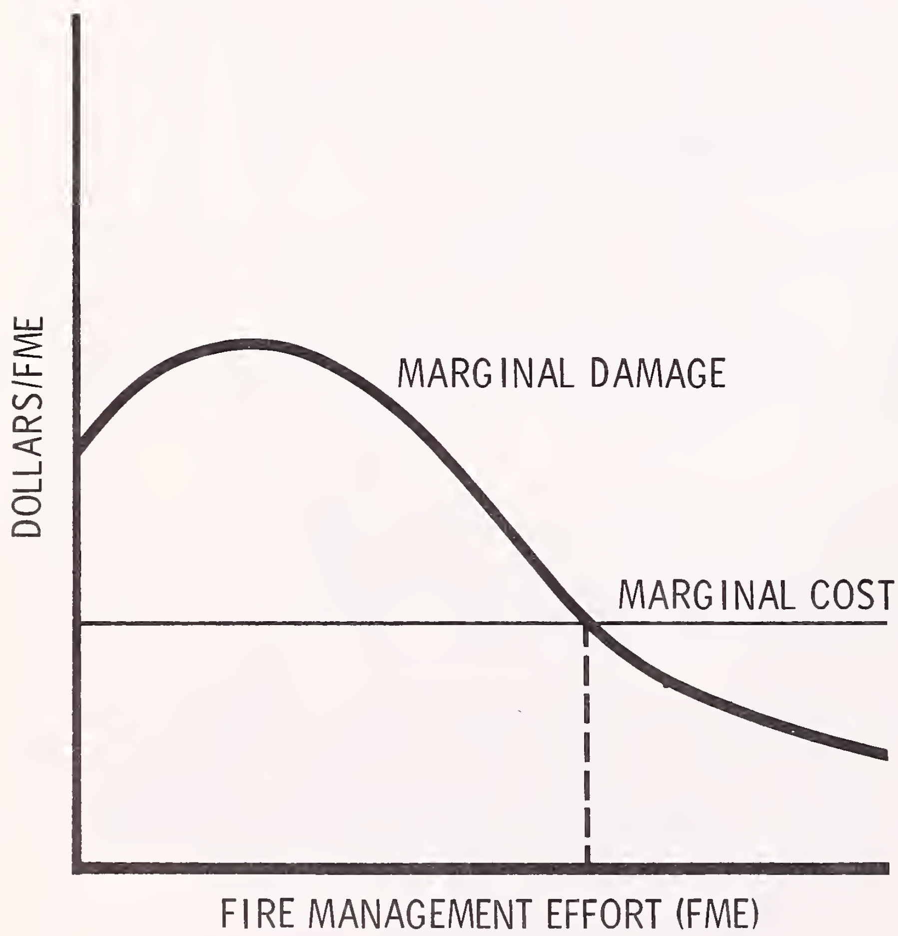

Figure 5.--Simard's marginal analysis model.

Least-Cost-Plus-Loss: Applications

With the exception of Sparhawk's and Craig's work, most of the literature in the preceding sections has not dealt directly with applications of the whole least-cost-plus-loss model. Some others have picked out parts of the model and tested them with available data--notably, Parks' cost module. However, these applications were only corollaries or parts of works dealing mainly with theory, so they were included with theoretical papers rather than empirical ones.

A few workers have suggested or tried strict application of least-cost-plus-loss. Broido and others (1965) compared two actual fires in terms of cost-plus-loss, using damage to insured property as the loss figure and adding suppression expenditures.

In heavily inhabited areas, of course, the loss figure turned out to be very high, thus Broido's statement:

> ". . .an almost self-evident conclusion: spending more money (on presuppression) can greatly decrease the area burned and also the total costs of fire. . ."

is logical, given the manner in which losses are calculated, and given that suppression costs are accepted as efficient and necessary. The authors of that article suggest that it is possible to simulate damages and suppression costs using operations research techniques to determine optimum suppression levels, though they are not specific about how to do it.

North, Offensend, and Smart (1975) analyze the marginal impacts of three protection alternatives applied to the semi-urban Santa Monica Mountains:

1. Limit the number of large fires by establishing better programs for prevention and initial attack.
2. Limit the extent of large fires using fuel breaks.
3. Reduce damage by making homes more fire resistant.

The authors compute cost-plus-loss for the current system and for each of three alternatives. Only Alternative 3 offered potential for improving cost-plus-loss. Perhaps the most significant feature of this study was the use of sensitivity analysis to test the impact of changes in the large number of assumptions that needed to be made. It was found that Alternative 3 remained attractive over a range of assumptions.

Gamache (1969) takes an approach somewhat similar to Simard's in attempting to predict optimum "units of suppression" to be employed on a seasonal basis. Gamache goes beyond his predecessors in that he attempts to use his model to provide a useful management tool; i.e., he develops a predictor of the optimal level of presuppression force using a simulator. Using Parks' model of initial attack for a range of presuppression levels, historic probabilities, and expert opinion, the simulator develops fire by fire estimates of cost-plus-loss according to a given presuppression force. It probabilistically determines fires per day (concurrent fires) and aggregates these to estimate an entire fire season. By running the simulator several hundred times, for each presuppression level, a cost-plus-loss curve can be generated, and an optimal solution determined. Gamache goes on to apply his technique to a case study.

Benefit / Cost Analysis

One of the most popular methods used to determine the financial feasibility of public and private projects is benefit/cost analysis. Briefly, benefit/cost analysis seeks to identify those projects which return some acceptable amount of satisfaction (income, flow of benefits) per unit of investment. Although, as previously discussed, this method is directly related to least-cost-plus-loss, only a few analysts have employed it because of the conceptual difficulty of measuring averted damages.

O'Connell (1971) suggested that instead of analyzing single options, all management alternatives should be treated by benefit/cost to identify marginal benefits and costs. He also cautions that all impacts (national, regional, and local) must be accounted for; this applies to users of both benefit/cost and least-cost-plus-loss. The framework he suggests is a series of iterations through a linear-programming model for various management alternatives with a feedback loop to assess the impacts of management itself. Though O'Connell does not discuss fire specifically, he is interested in natural resource planning, and his results are applicable to fire control planning.

Zivnuska (1972) asserts that benefit/cost should be used to choose between prescribed burning to meet a given objective and other types of management activities, using the argument that fire management should have to meet the same benefit/cost criteria as other projects. Like many other authors, Zivnuska recognizes the problem of valuing nonmarket commodities. He stresses the need for development of better methods and prescriptions.

Jischke and Shamblin (1974) have taken a unique approach to benefit/cost analysis by integrating it with elements of least-cost-plus-loss. The cost-plus-loss figure, they assert, can be used as the benefit/cost model, though they never explained how. Their approach gives particular attention to costs and does not specify the benefits or how to measure them. This article is part of a larger treatise that includes many specific attempts at benefit/cost analysis of wildland fire presuppression and prevention.

Allowable Burn Objectives

Many other authors who discussed allowable burn objectives are not included here because they seldom considered economic constraints. Some authors, however, have suggested that policy should be based on some kind of annual allowable burned acreage, developed through economic analysis.

Beichler (1940) preferred to select the allowable-acres-burned arbitrarily, but he suggested that it could also be done by equating resource losses and costs (though the economic logic behind this method is not provided). He was convinced that the allowable burn should be based on what he called "adequate" control and that adequate control should be related to resource value. However, he offers no objective means of arriving at either resource values or adequate control, though his feeling is that adequate control and "total fire exclusion" (except as a management tool) are not incompatible.

Hornby (1939) suggested using least-cost-plus-loss to develop an allowable-burn percentage of total area, though with no greater specificity than Beichler as to how to make this determination.

Gibson and others[7] take a much more innovative approach to allowable-burn determination. They suggest setting up a matrix of fire damage class and fire danger rating and determining (it is unclear as to how) an allowable-burned-acreage for each combination. These should then be compared with actual burned acreages and then revised if the actual burn is greater than the allowable. No reevaluation is suggested if the allowable burn is greater than the actual; apparently this is considered less critical. The revision, Gibson suggests, ought to take into account the productivity of the land, which resources are damaged, destroyed, or improved, and long- and short-term changes in resource outputs, tangible and intangible.

Other Objectives

Least-cost-plus-loss, benefit/cost analysis, and allowable-burn objectives account for the vast majority of literature having to do with economic guidelines for allocating resources to fire control or fire management, but occasionally someone suggests something different.

Flint (1928) and Coyle (1929) both thought that fire damage appraisal and protection could be assessed like other property for insurance purposes. Flint wanted to spend money on protection until forest property was "as safe from destruction by fire as other forms of destructible property." Coyle suggested much the same thing; that "property in the forest should have the same call on public moneys as urban property" by units of value (not necessarily acres). Coyle was actually one of the first to be concerned with spending money on protection of forests where resource values were not sufficiently high to justify the expenditure.

Davis (1965) thought that benefit/cost analysis of alternative protection systems was good in theory, but difficult to practice because of the difficulty of measuring the benefits of fire protection. In lieu of benefit/cost, then, he suggests using protection costs and wildfire activity patterns (including average acres burned, annual variation in acres burned, and probability of specific events such as Class E fires) and that a reduction in any or all of these indicates a preferable system. He then characterized alternative management schemes as feasible or infeasible, based on the above parameters. Smith (1971) takes somewhat the same approach in suggesting that cost-effectiveness of fire protection funds needs to be evaluated.

Nautiyal and Doan (1974) propose another alternative to least-cost-plus-loss based on indifference analysis. They suggest that allowable cut and protection are interdependent determinants of the forest manager's utility (satisfaction), in that both cause a "loss of green acres." The loss of utility associated with harvested acres, however, is lessened to some degree because revenues generated can be used to offset protection expenditures. These losses of utility are translated into iso-dissatisfaction curves, each of which shows the various combinations of green acres lost and net protection cost (gross protection costs minus timber revenues) resulting in a given level of dissatisfaction. In addition, the forest manager is faced with a "protection possibilities curve" which measures the rate at which he is able to trade expenditure on protection for acres saved from burning. This rate is a function of available protection technology. The authors claim that the best protection level is that which minimizes dissatisfaction at an "adequate" level, where the protection possibilities curve is tangent to an iso-dissatisfaction curve, rather than at the minimum cost-plus-loss (fig. 6). The difference between these two levels (in monetary terms) is a measure of the manager's value of nonpecuniary commodities. This model can be extended in that the manager can further reduce dissatisfaction by increasing both

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[7]H. P. Gibson, Lance F. Hodgin, and John L. Rich. 1976. Evaluating National Forest Planning Methods and Measuring Effectiveness of Presuppression Expenditures. USDA For. Serv., East. Reg. Mimeo.

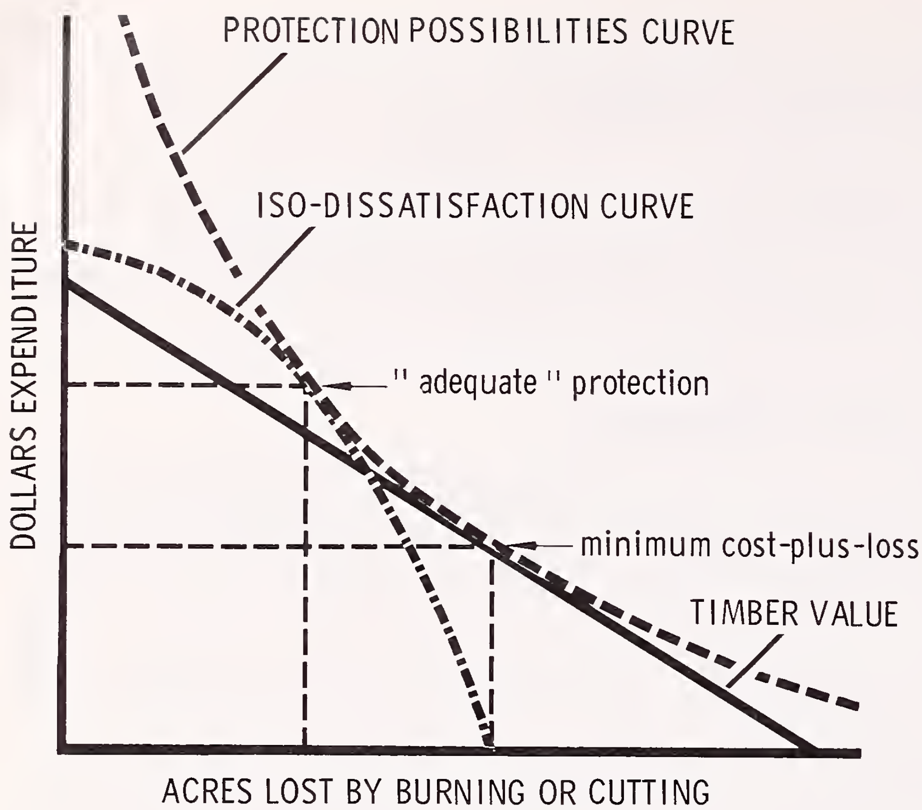

Figure 6.--Nautiual and Doan's indifference analysis model.

protection expenditures and allowable cut. Planned cut is then increased until the lowest possible iso-dissatisfaction curve is achieved. Intuitively, the manager is trading harvested acres for burned acres and offsetting protection costs with timber sale receipts.

Status of Economic Guidelines for Investment in Fire Management

The foregoing sections indicate that several approaches to an economically justifiable level of fire control expenditure have been developed. However, the National Forest System is not using any of these approaches. The Forest Service Manual provides that:

> "The overall objective of fire control is to provide protection to an intensity commensurate with public safety, values, hazards, risks, and management objectives involved. This includes holding fire losses (cost and damage) to a minimum. . ." (USDA For. Serv. 1972a).

This is in accord with least-cost-plus-loss methods and can also be accomplished using other methods. However, the policy that guides fire management planning is as follows:

> "The basic fire control policy on National forests and National Grasslands is to provide well planned and executed fire prevention and presuppresion programs with aggressive suppression action when fires occur" (USDA For. Serv. 1970).

The policy statement is potentially in conflict with the objective; aggressive suppression may be inconsistent with minimizing the sum of cost and damages.

Ed. Note: Revision of fire management policy has brought changes in suppression policies as well. The objective of fire suppression is to control wildfire (fast, thoroughly, and safely) at reasonable cost to meet land management objectives.

The National Forest System is following the policy, with little on-the-ground emphasis on the objective. One reason for this is that fire expenditure evaluations, specifically the Monthly Fire Report (USDA For. Serv. 1973a) and the Annual Regional Fire Report (USDA For. Serv. 1973b), do not include damage totals. The reports emphasize the number and size of fires and the costs of suppression. The reports evaluate both plans and personnel accordingly. Fire planning does include damage potentials; however, from an economic viewpoint, damage forecasts are often both exaggerated and incorrect. First, estimates of damage resulting from fire typically assume that 100 percent of damage potential always results (USDA For. Serv. 1972a). This assumption provides for an overestimation of damage. The use of damage potentials is incorrect in calculating loss; "loss consists of suppression cost plus resource damage plus restoration or rehabilitation" (USDA For. Serv. 1972b, p. 43). Including both damages and restoration or rehabilitation costs double-counts the losses. Rehabilitation cost, restoration cost, or replacement cost is another measure of the resource loss.

Because of the methods used in planning and evaluation, the emphasis has been on reducing acres burned, by implementing the policy of aggressive suppression. From an economic standpoint, this system of planning and implementation may be biased; from a political standpoint, however, it may be necessary or, at least, acceptable.

The economic wisdom of aggressive fire suppression has been questioned more and more frequently in recent years. Many of the methods outlined in the preceding sections could, theoretically, provide some of the answers to questions dealing with how much should be spent on protecting forests from fire. But this is only in theory. Application of least-cost-plus-loss, or benefit/cost, or the indifference-analysis usually requires nonexistent data or the acceptance of some truly heroic assumptions, which may at least in part account for the absence of a coordinated attempt to use these models.

Some of the most doubtful of these assumptions deal with production relationships. Almost all the models begin with the argument that increased fire management results in a steadily decreasing loss, either in dollar loss or acres burned. In other words, the first step involves defining a function for relating inputs of fire management effort to reductions in losses. Such functions are never specified numerically, because the relationships are simply not known. Furthermore, there are as many of these relationships as there are combinations of fuels, weather, topography, hazard, risk, and efficiency of the fire-control effort. Zivnuska (1972) sums up the problem by saying:

> ". . .if production relationships have not been established, the economist has no basis for proceeding with an analysis and instead must fall back on two alternatives, neither of which is particularly satisfying. He may resort to the building and analysis of models of fire management. . . Alternatively, he may try himself to develop estimates of the physical production relationships, in which case he quickly moves out of the area of his specialized competence."

This statement illustrates the second major problem associated with the available economic models. As Zivnuska implies, models are built around assumed or hypothetical production functions because to specify such functions requires expertise that an economist does not possess. Even in terms of so rough a measure as acreage, production relationships are undefined, and acres are only a first approximation, anyway. To be truly representative of value, burned acres should be translated into reductions in or damage to commodities and services derived from the forest resources and from these into dollar losses. None of these functions or translations is available; and as a consequence, most of the literature is either entirely theoretical or very limited in its approach to value. Many authors, including Sparhawk and Mactavish, suggest using discounted timber stumpage values as a measure of value lost. Others recognized that many other kinds of damage could occur, but only Craig and Gamache attempted any complete quantification. Many times, too, the values used were crude or arbitrary ones because there is no procedure for deriving anything better.

Another shortcoming of most of the economic models applicable to fire control is the lack of recognition given to beneficial effects of fire. Only the models of Simard and Gamache recognize that fire could have desirable economic effects. Davis and Boster realized the problem but did not develop methods for estimation. Most of the literature is concerned solely with fire protection and damage, rather than with net losses or net effects. As a result, most models probably overestimate the expenditure to be made on protection.

Even with all its shortcomings, economic analysis has a recognized place in fire management. At a fire policy meeting of regional foresters in July 1977 (USDA For. Serv. 1977), a significant step was taken in modifying the aggressive-suppression thinking associated with the 10:00 a.m. policy. The new suggested policy on escaped fires is "control strategy that minimizes cost plus net loss." This will not instantly solve all problems, of couse, and implementation of the new policy will require that a lot of background work be done. The available methods are not sophisticated and will not come up with perfect answers. The best that can be hoped for, at least in the near future, is planning of control strategies prior to a fire occurrence in a noncrisis situation where alternatives can be analyzed in depth.

APPRAISAL OF FIRE EFFECTS: CONSIDERATIONS AND METHODS

Throughout the history of fire control and fire management planning and throughout the literature concerning how and why to do such planning, the problem of evaluating fire effects both physically and monetarily comes up repeatedly. Because of the scanty attention given to beneficial effects of fire and the tendency of large fires to cause obvious destruction, this whole subject area has come to be known as damage appraisal. Little has been published on damage appraisal techniques. Although many authors state that damage appraisal must account for all fire effects on all resources and that the subject deserves further research, few have attacked the problem specifically. Mitchell (1954) stated that damage estimates should be based on the "depreciated present worth" of the resource in question. Tangible and intangible items, he suggests, need to be separated; and appraisal methods need standardization. Finally, Mitchell states that sound and realistic methods for valuing intangibles are "essential."

The first attempt at damage evaluation was by Sparhawk (1925), who used stumpage loss as a measure of fire damage. He did not consider quantifying other values affected by fire. Lindenmuth and others (1951), in developing damage appraisal procedures and tables for the Northeast, stated that fires affect watershed, wildlife, soil, recreation, and other values. Owing to the lack of research, they added a $1 per acre loss onto timber losses to approximate the losses of these other resources. Craig's (1945) work was broader in scope: he attempted to evaluate damage to other forest resources as well as to timber. To assess the loss of timber value, Craig advocates using delay to future returns caused by mortality and cull, growth reduction, and stand decomposition rather than replacement cost. With respect to watershed value, Craig identifies two critical factors: (1) fire-caused damages from upland erosion, flood, and sediment, and (2) reduction of groundwater supplies. He then goes through a step-by-step process to factor out all effects on watersheds not attributable to fire and to tie the applicable effects to specific fires and quantify them in terms of value lost or injury sustained by users of water. Wildlife damage is compartmentalized into damage to

animals and damage to habitat, measured in terms of dollars-per-animal figures set by the State. How the State arrived at these is not revealed. Losses to organized and dispersed recreation are measured in terms of reductions in income from fees, licenses, and the like. Other damage (forage, forest products, property, loss of life, temporary interference with lifestyles, etc.) Craig simply takes from fire wardens' reports.

In spite of all the shortcuts, Craig's appraisal remains one of the more complete reports. The next efforts were by Mactavish and Marty, both in 1965. Marty identified five ways to measure losses due to fire. The first is to use market prices, applicable only to those commodities with readily available markets. A second method is to determine replacement cost. Another way is to discount future expenses and incomes at the appropriate interest rate. The fourth method is to calculate the "conversion return"--finding a product with a market price and deducting processing costs and profits for intermediate processing. This technique would be applicable to such commodities as stumpage and forage. Marty's fifth method is to determine the opportunity cost, calculated by either the user's cost to obtain the goods or services or the income foregone by the supplier in providing them. Marty recommends this technique for nonmarket commodities. Mactavish identified only timber values lost, choosing the net present value of future harvests lost minus salvage as the best method to estimate timber damage. McLean (1970) also confines his appraisal to timber value, his primary goal being to develop a method of evaluating damage to immature timber. He, too, argues that the present net worth of the expected harvest value should be used to evaluate how much is lost when an immature stand is burned. When the stands are underutilized or overstocked, an estimated percentage of the expected stumpage value should be used instead. The damage figures are developed by subtracting the expectation value of bare land (assuming all timber is lost) from the expectation value of the stand before fire.

Harrison and North[8] compiled a matrix of fire effects to be considered in damage appraisal, though they do not attempt to value any of them specifically. Resource categories are timber, range, soils, water, property and improvements, health and life, wildlife and recreation, smoke, and hazard from future fires. The values affected include owner values, user values, and externalities. The list is complete, and while an individual fire may not affect all categories, all should be considered.

The literature dealing with the least-cost-plus-loss approach usually suggests that fire damages and effects are measurable. Almost all the authors who deal with the subject assert that numerous problems are associated with such measurement, though few of them attempt to deal with the problems directly. Because timber (and sometimes forage) values are established by market processes, many of the writers have used these as estimators of resource value, preferring to ignore less tangible effects. Others have suggested using acres burned to indicate resource damage. Williams (1969) commends this alternative as "wise", due to lack of information about monetary losses, and suggests using an operations research-linear programming approach to allocate fire control money. Noste and Davis (1975) spell out why they think damage appraisal is so difficult. The problem, they assert, is complex because many of the resources protected have nonmarket values and because it is difficult to say which resources will be threatened by fire and how much damage or benefit these resources may sustain as a result of fire. They also question whether economic analysis of fire effects will actually be used in an unbiased fashion in allocating resources to fire management activities. Historically, they maintain, money invested in fire control has not paid off; however, it should be recognized that little economic analysis has ever actually been done and applied to real-world fire problems.

Even more recently, a task force made up of USDA Forest Service planners concerned with economics in fire management planning (Chandler 1977) reiterated that fire damage

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[8]J. Michael Harrison and D. Warner North. 1972. The economic assessment of fire effects: a first look at the problem in southern California. Stanford Res. Inst. Proj. Memo. 1555-3. June 14, 1972. Menlo Park, Calif.

appraisal is "hideously complex" due, at least in part, to the nonmarket values and the lack of critical data. There are three general data needs that the task force identified: the relationship between fire size-intensity and various kinds of suppression activities, a model of how fire size-intensity affects commodity flows, and specific relationships between physical and monetary commodity flows.

Brown and Boster (1974), Brown and others (1974), Davis[9], and Gale (1976) all measure fire management benefits in the same terms: the benefits of fire management are values at risk (value protected) minus actual damage, where actual damage is calculated for the area both with and without fire management. Vasievich (1976) used a similar approach for evaluating the cost effectiveness of prescribed burning in the South. All of these approaches fit into the least-cost-plus-loss model in that they are concerned with movements along the cost-plus-damage function and shifts in the curve itself. Flint (1924) takes an approach similar to this in measurement of fire damages: the value of resources before fire less the value after fire is an indicator of damage.

Gisborne (1939) suggested a stepwise approach to a measure of total danger:

1. (rate of fire spread) x (dollar damage per acre) = dollar damage per hour,
2. (dollar damage per hour) + (control expenditure per hour) = dollar cost per hour,
3. (dollar cost per hour) x (fire occurrence index) = total danger.

Gisborne's "total danger" approach, applied to some management unit, simply assumes that the most unattainable piece of information (dollar damage per acre) is either available or can be developed.

In 1966, Countryman recommended a similar approach to damage appraisal. He states that damage rate is proportional to susceptability to damage. He goes on to say that some resource damages are linearly related to fire size, such as timber and forage losses, while other damages are exponentially related. He cites a watershed study in southern California where watershed damages increased by more than 40 times when fire size increased by 20 times. However, Countryman does not propose how to identify the relationships between fire size and resource damage.

In 1975, Bakker did a very complete financial analysis of actual fire effects on a watershed in northern Washington, identifying primary and secondary effects both on the watershed and in affected local areas. Timber losses were measured by present net worth of stumpage-less-salvage value, as well as in the effect of changed harvests on the local logging industry. Water yield and sediment were the parameters used to evaluate fire effects on watershed; the value of increased water yield was measured by the value of additional power it generated and increased sale of water for irrigation. Increased sedimentation was valued by damage to all direct water uses that were affected. In addition, he included property damages caused by fire-related mudslides. Recreation values were estimated by multiplying the change in use (in visitor days) by values per visitor day developed for various kinds of recreation in a study by Dyrland in 1973. Wildlife values were evaluated in much the same manner, using the change in visitor days of hunting and fishing caused by changes in animal and fish populations due to fire. Property and improvements were evaluated by individual replacement value. Other effects (which turned out to be insignificant in this case, according to Bakker) were identified to be impacts on grazing, research, and air pollution, and on emotional, aesthetic, and educational values. Losses of life were evaluated using the statistical value of a life determined by the U.S. Department of Transportation.

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[9]Lawrence S. Davis. 1974. An exploration of the economics of fire management programs in the Rocky Mountains with emphasis on information needs. (Draft.) April 12, 1974.

Bakker's analysis is one of the most complete treatises available for fire damage appraisal and is oriented more toward specific application. An analysis by Crosby (1977) is more theoretical. Both analyses are adaptable; and more important, both consider that fire effects may be beneficial as well as harmful. Crosby is most concerned that all effects be evaluated in light of land management objectives to serve human needs. He emphasizes that the critical evaluation is the "value protected," or those values that are potentially destructible by fire. This, he asserts, is less than the total resource value. Fire is incapable of "destroying acres," in the vernacular of countless fire reporters; it cannot remove acres from the face of the earth. Crosby then directs his efforts toward developing step-by-step methods for evaluating the impacts of fire on forest and wildland recreation, wildlife, property, human comfort and convenience, aesthetics, the atmosphere, water, watersheds, timber and the timber industry, and range. In some cases where values are nonpecuniary, he develops methods of ranking damage in an ordinal fashion and suggests using arbitrary value classes corresponding in magnitude to the importance of the ranking.

Brown and Boster (1977) have described an alternative to the present-net-worth-of-harvest-expected methods in valuing timber losses. The method, known as the "with and without" approach, had been known for a few years, but was not specifically related to fire effects. Basically, it spreads the impact of lost timber harvests over the entire management area in terms of the effect of future harvests and harvest values. This method realizes, as does the Nautiyal and Doan approach, that there is more than one management alternative and that the forest manager may trade alternatives against one another to change the immediate impact. Unless the whole management area is lost, the manager may postpone or soften the immediate impact of fire by rearranging harvesting schedules on the rest of the unit for, if necessary, the entire next rotation to reduce the present value of the impact of timber lost.

Status of Fire Effects Appraisal

Attempts at comprehensive damage appraisal are frustrated by the difficulty of placing a value on nonpecuniary goods and services such as recreation values, wildlife values, and aesthetic values. In most instances, the physical effects of fire on resources are not known. Even if they were, the problem of valuing them is no less difficult. All that can be said is that wildlife, for example, has some value because people desire it. In any context, valuation of such nonmarket amenities is difficult. Some approaches have relied on giving such amenities an ordinal ranking; Crosby uses this method. But if the valuation is being used to define dollar expenditures, a problem still exists. This can be solved by applying arbitrary dollar amounts to different rankings, in which case the value in question may or may not represent the resources' real value to society.

Timber, wood products, and forage are traded in markets and, therefore, have market-determined values; but the problems of defining loss or benefit are still not solved. The market stumpage value for instance, is really only applicable on management units that are operated to maximize profit, which the Forest Service is legally prohibited from doing. So, because the full allowable cut is not always cut (recognizing that allowable cut is not determined on the basis of an economically optimal rotation), how can timber loss be evaluated? Unless the timber is actually scheduled for harvest, and assuming that there are reserves of timber which can be harvested, it is arguable as to whether the full discounted stumpage value is really lost. Furthermore, discounted value itself is a rather unreliable measure of value given the long investment periods involved in much of forestry, the difficulty in defining the "correct" discount rate, and the unreliability of prices in the short run.

Another problem associated with damage appraisal is how to treat off-site values. For example, smoke may cause people great temporary inconvenience, damage to watersheds can contribute to downstream flooding and damage to water quality, highways and transportation systems may be upset, and so forth. The effects may be benefical, too; increases in water runoff due to fire may generate additional hydroelectric power. In any case, evaluation of these off-site effects is fraught with difficulty, as is any other facet of damage appraisal.

In short, damage appraisal is an inexact science, but the information yielded by an appraisal is necessary for evaluating the benefits of fire management. We find ourselves in agreement with those who suggest that more work be done on developing acceptable methods for damage appraisal.

SUMMARY

Economics is concerned with allocating limited resources to meet unlimited goals. In fire management, the limited resources are the funds available to meet fire management objectives. Historically, these resources have not been limited, through the use of FFF funding. With this funding procedure and the 10:00 a.m. policy calling for aggressive fire suppression, it is possible to exceed protection commensurate with resource values--the objective of fire management. Concern for the economic justification of fire management expenditures was first expressed in the 1920's and 1930's. It quieted after the adoption of the 10:00 a.m. policy, until the 1960's when the concerns resurfaced. In 1977, the USDA Forest Service altered its policy to more closely conform with the objectives of fire management.

Several models have been proposed as economic guidelines for determining fire management expenditures. The most widely discussed model is least-cost-plus-loss. This model defines optimal protection as that level which minimizes the sum of prevention, presuppression, and suppression costs and resource losses. The costs and losses are generally assumed to vary predictably with presuppression expenditures, fire management effort, acres burned, or some other independent variable.

Benefit/cost analysis is another model that has been proposed. It can be used to determine the economically optimal level of funding, as with the least-cost-plus-loss model. When the benefits are calculated as the difference between values protected and actual damages, benefit/cost analysis will yield results identical to the results of least-cost-plus-loss. One advantage of benefit/cost analysis, however, is that it can be used to examine marginal expenditures; a benefit/cost analysis for a particular fire management project is comparable to similar analyses for projects in other resource areas. This is a useful advantage for determining short-run changes in fire management expenditures.

Several other models have been proposed. The allowable burn objective is common in the literature, but there is very little discussion of the economic rationale for this model. Other suggestions include protection to bring forests to an insurable level commensurate with other property, measuring wildfire activity patterns instead of resource losses, and using indifference analysis (a theoretical economic model with less applicability than benefit/cost analysis or least-cost-plus-loss).

It is difficult to apply any of the models discussed above. One problem is that all of the models assume that there is a known relationship between fire management and resource losses. In actuality, the relationship is not known; in fact, there has been

some question as to the nature of the relationship. Questions arise as to the linearity of the relationship between acres burned and resource damage. It is even possible that acres burned and fire management efforts are not correlated, or at least there is no evidence of the relationship in the literature.

A second problem in applying the economic models is that all assume that resource losses are measurable. However, this measurement is given scanty attention in the literature. Often times, only timber or timber plus forage are used as resource losses. Even in timber, there is room to question the amount of loss when a tree burns; is the current market value lost if the tree was not marked for immediate sale; if not, what is the appropriate discount rate to use for future market values; what are future market values going to be? There are also problems arising in the measurement of nonmarket goods and services. Precise values are virtually impossible to determine, and it is difficult to determine values that are acceptable to all or even many of the affected parties. In addition, there is the problem of determining off-site damages; what is the loss due to soil movement, water pollution, and air pollution? This is an area that needs substantial research before progress in the field of fire economics can be made.

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APPENDIX

Nonfire Related Resource Valuation Models

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Discusses both the historic and contemporary influences of economic in formulating USDA, Forest Service fire management policy in allocating money for fire management and in appraising fire effects. Includes a partial listing of publications that deal with resource valuation.

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Headquarters for the Intermountain Forest and Range Experiment Station are in Ogden, Utah. Field programs and research work units are maintained in:

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